AFRL-HE-WP-TP-2006-0039

AIR FORCE RESEARCH LABORATORY

Military Display Market: Fourth Comprehensive Edition

Daniel D. Desjardins
Darrel G. Hopper

Human Effectiveness Directorate
Warfighter Interface Division
Wright-Patterson AFB OH 45433-7022

February 2006

20060403507

Human Effectiveness Directorate
Warfighter Interface Division
Wright-Patterson AFB OH 45433

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
February 2006

2. REPORT TYPE
Technical Paper

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Military Display Market: Fourth Comprehensive Edition

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Daniel D. Desjardins, Darrel G. Hopper

5d. PROJECT NUMBER
7184

5e. TASK NUMBER
11

5f. WORK UNIT NUMBER
26

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Materiel Command
Air Force Research Laboratory
Human Effectiveness Directorate
Warfighter Interface Division
Wright-Patterson AFB OH 45433-7022

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/HECV

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-HE-WP-TP-2006-0039

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
This will be published in the Proceedings of the SPIE Defense & Security Symposium Conference. The clearance number is AFRL/WS-06-0614, cleared 6 March 2006.

14. ABSTRACT
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15. SUBJECT TERMS
Displays, technology transition

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER (include area code)
UNC	UNC	UNC	SAR	18	Darrel G. Hopper (937) 255-8822

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18

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Daniel D. Desjardins and Darrel G. Hopper

Air Force Research Laboratory

Address: Bldg 248 Rm 300, 2255 H Street, Wright-Patterson AFB OH 45433-7022 USA

DDD Telephone: 937/255-4079 *Fax:* 937/255-8366 *E-mail:* daniel.desjardins@wpafb.af.mil

DGH Telephone: 937/255-8822 *Fax:* 937/255-8366 *E-mail:* darrel.hopper@wpafb.af.mil

ABSTRACT

The military display market is analyzed in terms of all fully electronic and many electro-mechanical displays used on combat platforms across all DOD Services. The military market for displays is defined by parameters such as active area, bezel-to-bezel measurement and technology. Other characteristics such as luminance, contrast ratio, gray levels, resolution, viewing angle, color, video capability, and night vision imaging system compatibility are noted. This study takes into account all displays that are either installed or funded for installation. In some few cases, it also includes planned displays, such as for F-35.

Display sizes having aggregate defense applications of 5,000 units or greater and having DOD applications across 10 or more platform fleets, are tabulated. The issue of size commonality is addressed where distribution of active area across platform fleets, individually, in groups of two through nine, and ten or more, is illustrated. Military displays are also analyzed by technology, where total quantities of such displays are broken out into CRT, LCD, AMLCD, EM, LED, Incandescent, Plasma and TFEL percentages. Custom, versus rugged commercial, versus commercial off-the-shelf designs are contrasted. High and low information content designs are identified. Displays for several high-profile military programs are discussed, to include both technical specifications and program history. Our defense-wide study as of February 2006 has documented 1,195 direct-view and 15 virtual-view display sizes across 628 weapon system platforms for a total of 1,13[redacted] total displays.

1. INTRODUCTION

This paper provides an up-to-date overview of the DOD display market, providing government and industry highlights of information provided in the up-coming 742 page "Military Display Market: Fourth Comprehensive Edition" technical report. A key purpose of this study is to facilitate government incentives and industry investment by which to meet future demand. Timely decisions on this score can avoid adverse market phenomena such as vanishing vendor syndrome and sole vendor dependencies while enabling positive trends such as technology transition and commonality. This study, current as of February 2006, suggests DOD display needs will exceed 1,134,000 over the next 15 years. Direct-view displays, to include large-area command and control applications, are in excess of 906,000. Virtual-view displays, including Head-Up Displays (HUD), Helmet-Mounted Displays (HMD) and Night Vision Goggles (NVG), are in excess of 224,000. Of these, some 17,700 are miniature displays, either CRT (currently), or AMLCD and AMOLED (future). The detailed report is available to qualified requesters. [1]

2. STATUS

This is the fourth comprehensive report in a series of releases beginning 1997. At that time we published an interim report, followed by comprehensive editions in 1998, 1999 and 2002. Beginning 1991, we began inventorying the number, function and size of military displays as a means to determine the industrial base (what level of display capability was being delivered to which programs), as well as to identify opportunities for technology insertion. Initially the focus was tri-service aircraft cockpits. By 1995, the focus was enlarged to encompass all displays for all combat platforms. The 1997 interim report covered 132 platforms and identified some 157,000 displays. The first comprehensive edition in 1998 covered 263 platforms and identified some 242,000 displays. The 1999 second comprehensive edition covered 350 platforms and identified over 322,000 displays. The third

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* Citation: Daniel D. Desjardins and Darrel G. Hopper, "Military display market: fourth comprehensive edition," in ***Defense, Security and Cockpit Displays III***, Darrel G. Hopper, Editor, SPIE 6225A, paper 3 (2006).

comprehensive edition (2002) identified 403 combat platforms and comprised an aggregate of over 382,500 displays. The present report, our fourth comprehensive edition (2006), presents data on 628 platforms and covers some 1,134,022 displays. A number of platforms and stand-alone systems remain to be incorporated in future reports. On-going effort will be required not only to achieve reasonably complete coverage of the military display market but to account for updates to already identified systems.

3. BACKGROUND

The DOD display market depends upon the authorized force structure. At the time of our third comprehensive edition study in 2002, DOD was in the process of downsizing. However, spurred by the global war on terror, the DOD budget has more recently been on the rise, going from $364.6B in FY2003 to $401.7B in FY2005. Research and development investment, and procurement expenditures, have risen as well. Two comprehensive initiatives have significantly impacted future budgets: The DOD U.S. Global Defense Posture Review and the 2005 Base Realignment and Closure (BRAC) Commission. DOD's Global Defense Posture Review looked at all aspects of America's global defense posture, to include personnel, infrastructure, equipment, sourcing, and surge capabilities. The goal was to ensure U.S. military capabilities are configured for optimal deployment, meeting the challenges of the new global strategic environment. The BRAC 2005 commission made recommendations critical to streamlining DOD facilities and save billions of dollars that would be better spent on transformation. The transformation of America's military capabilities involves developing and fielding new military systems to decisively combat the full range of security threats now and in the future. A key objective is to provide robust capabilities and innovative approaches for the full spectrum of potential missions. For example, unmanned aerial vehicles continue to provide new capabilities and advantages that have proven critical in the global war on terrorism. Transformation will continue to require a strong science and technology (S&T) program. The fiscal 2005 S&T request is $10.5 billion, a 1.6 percent real increase over the fiscal 2004 request.

The FY2005 DOD budget adds $3.2 billion to support the transformation of the Army by fully funding the Future Combat Systems (FCS) and $1.0 billion to procure combat vehicles for the 5th Stryker Brigade Combat Team (SBCT). The fiscal 2005 budget supports the fielding of the 4th SBCT and sustains the three SBCTs already in the force. The U.S. Navy will receive $11.1 billion to support procurement of nine ships in fiscal 2005 – up from seven ships for fiscal 2004. Included are funds for the first procurement of the new DD(X) destroyer and Littoral Combat Ship. Regarding air assets, the EA-18G will receive $0.4 billion to develop the next generation solution to detect, identify, locate and suppress hostile emitters, providing electronic attack and information operations capability against integrated air defense systems. The F-35 Joint Strike Fighter (JSF) program will receive $4.6 billion to provide for cost growth in its system development and demonstration (SDD) phase. Additionally, the V-22 program will receive $1.7 billion to support on-going development and procurement of 11 aircraft. These assets, brought into play by an increase to the DOD budget for FY2005, become part of the authorized force structure and necessarily drive increases to the display market. For example, a fifth Stryker brigade will entail approximately 350 vehicles and some 3,400 displays. A destroyer class ship requires as many as 350 custom and commercial-off-the shelf displays. By contrast, as many as 2,600 20 x 8 in. AMLCDs and 5,200 0.968 in. diagonal AMLCDs are projected for the direct-view F-35 Panoramic Cockpit Display and the virtual-view F-35 Helmet-Mounted Display, respectively. This does not include spares. Eleven V-22s, depending on the mix of variants, represents as many as 276 fully electronic displays (again, not including spares).

A rising DOD budget facilitates investment for nascent technologies to meet future DOD needs. It will also spur needed replacement of vanishing vendor-afflicted cathode ray tube (CRT) and electromechanical (EM) displays and thereby save logistics dollars by achieving 12:1 return on investment (ROI) relative to implementation of flat panel displays (FPD). The Vanishing Vendor Syndrome for CRT and EM displays manifests itself in terms of unavailable assets that cannot be delivered either to a train/equip command such as Air Combat Command, or dispatched to a using command such as USSOCOM or CINCPAC. Fortunately, both industry and DOD have learned the lessons of the single-vendor scenario for active matrix liquid crystal displays (AMLCD) which existed in the days of Optical Imaging Systems (late 90's), followed by Planar dpiX (ending 2001). The single-vendor model impacted deliveries and readiness regarding the Color Multi-Purpose Display for AH-64D, the Heading & Hover Situation Indicators for CH-46E and the Engine Indication and Crew Alerting System / Control Display for V-22. Aircraft primes such as Lockheed Martin are now positioning themselves to become their own alternate source for displays affecting platforms they are upgrading, e.g., MH-60S and MH-60R.[2] Meanwhile, Northrop Grumman, another aircraft prime, is itself a display vendor.

4. METHODOLOGY

The primary method for gathering information on individual electronic display systems for this study has been to make direct contact, either by e-mail or telephone, with program managers in industry or government. This can either be the system program office on the

government side, else the systems engineering office on industry side. There are two levels of enquiry: matters pertaining to the number of platforms, display suite composition, numbers of displays per platform suite, number of platforms fielded or on contract for delivery, design review milestones, production delivery schedule, etc. are addressed through the program manager's office. Issues pertaining to performance parameters, e.g., active area, resolution, viewing angle, luminance, temperature range, Night Vision Imaging System compatibility, display technology, etc., for individual displays, are addressed through the principal or lead engineer's office. Approaching the program manager or lead displays engineer on government side seldom leads to engineering data, but is the appropriate point of departure as far a protocol. Most hard data of an engineering nature, admittedly, comes from private industry. In this regard, contact is usually made first with the prime contractor, e.g. General Dynamics Land Systems for Stryker, Lockheed Martin for C-5 AMP, with actual display data obtained through the display sub-contractor, e.g., Kongsberg for the Stryker Remote Weapons Display, Honeywell for the Multi-Function Display Unit on the C-5 AMP. Aside from these sources, literature reviews are conducted to stay abreast of developments for existing display related programs, as well as for identifying new starts. Literature reviews include publications such as *DefenseNews*, *Avionics Magazine*, *Aviation Week & Space Technology*, *International Defense Review*, etc. Until 2003, many on-site visits facilitated gathering data for large platforms, e.g., Navy surface vessels, or fleets of platforms such as Army's Fourth Infantry Division. However, in recent years these have been less frequent due to funding restrictions. The degree of telephonic, e-mail, fax and person-to-person contacts for the fourth comprehensive edition is attested by the some 1300 endnotes to the report.

5. RESULTS, DISCUSSION, AND ANALYSES

The "Results" section of the military display market report comprises summaries for each platform comprising a table and discussion. The results section entries are organized into the Categories and Groups. Category I comprises systems that shoot or get shot at and entail the following Groups: A. Fighter/Attack, B. Land Vehicles, C. Dismounted Combatants, D. Downed Pilot, E. Maintenance Equipment and F. Head or Helmet-Mounted. Category II comprises systems that are found in a combat environment but require less sunlight readability, and include the following Groups: G. Underwater Vessels, H. Bombers, I. Helicopters, J. Sensor/Surveillance Aircraft, K. Water Surface Vessels, L. Cargo/Tankers, M. Trainers and N. Experimental Aircraft. Category III comprises systems that operate in a non-combat environment and require low sunlight readability. Groups here include O. Unmanned Vehicle Control Stations and P. Command and Control Centers. Each platform table includes six columns: Display Type, Size, Number, Platforms, Total Displays and Present Technology. "Display Type" means the system display alpha-numeric designator or generic acronym. "Size" for fully electronic displays is the active area (inner-bezel) measurement, while for electromechanical displays is the outer-bezel measurement. It is always given in both metric and English with units of millimeters (inches) in the dimensional format of (a) horizontal x vertical (HxV), (b) diagonal, or (c) diameter, based on how the data came to us. When we ourselves took the measurements, we always used the preferred format, HxV, for rectangular displays. Metric units are preferred and given first. "Number" is the count of a particular type found on-board a given platform (aircraft, ship, land vehicle, command center). "Platforms" is the fleet size (number of vehicles in inventory or on contract for delivery). "Total Displays" is number of a given type for a given platform fleet (product of previous two entries). "Present Technology" is an acronym such as EM (electromechanical), CRT (cathode ray tube), or AMLCD (active matrix liquid crystal display).

The "Discussion" section for each platform comprises a more thorough description for each installed display in terms of defining performance capabilities, ideally, for the following parameters: maximum and minimum luminance (in lux or footLamberts), contrast ratio under specified ambient illumination for max. luminance and min. luminance, number of gray levels, horizontal and vertical viewing angles, resolution (pixels or lines horizontal x vertical), Night Vision Imaging System compatibility (rated by Type and Class), 1976 CIE chromaticity coordinates for white, red, green and blue (to include error margin), operating and non-operating temperature limits, operating and non-operating altitude limits, shock and vibration. In addition, the discussion typically address key program issues, such as program milestones (PDR, CDR, etc.), delivery dates, delivery rates, initial operating capability, technology transition decisions, and performance or maintenance issues. Not all platform files are complete in this regard, especially for surface and undersea vessels.

"Analysis" entails the integration of display data by size, technology, information content or other criterion. Various summary information is thereby made available. For instance, in the current paper we rank-order the most quantitative display sizes, identify the percentage market share of DOD displays by technology, show the distribution of DOD display sizes among one or more programs, and demonstrate the degree of "low" and "high" information content displays used by each DOD platform group. Because the "Discussion" also addresses other issues such as whether a display is manufactured according to military or commercial standards, we are also able to summarize information on industrial base. Further analyses allows us to gain particular insights, such as size clustering. An example of cluster analysis is found in this paper, and also in previous publications by Desjardins and Hopper. [3,4]

6. SUMMARY

6.1 Sizes

As of February 2006 our study has revealed the use of as many as 1,210 display sizes across the scope and breadth of all DOD weapon systems platforms. The distribution of sizes across platforms is illustrated in Figure 1. Some 679 of these 1,210 display sizes are unique (56.1%); that is, they are used by just one platform. Furthermore, 93 of the 1,210 unique sizes are "singularities"— just one of that size exists in DOD inventory. We recognize that, short of an instrument panel re-design (partial or full), existing crewstation configuration imposes a severe limitation to display size conversion in many programs. Some 60 sizes are used on 10 or more DOD platforms. Also, 471 sizes are used on 2 to 9 platforms. Some 28 sizes are used in aggregate quantities of 5,000 units or more; of these, 4 are unique to a single platform, 7 are used by two to nine platforms, and 17 are used by ≥ 10 platforms. Also, 32 sizes are used in aggregate quantities of less than 5,000 units, but by ≥ 10 platforms. Caveat: the same size on different platforms is frequently a different line replaceable unit.

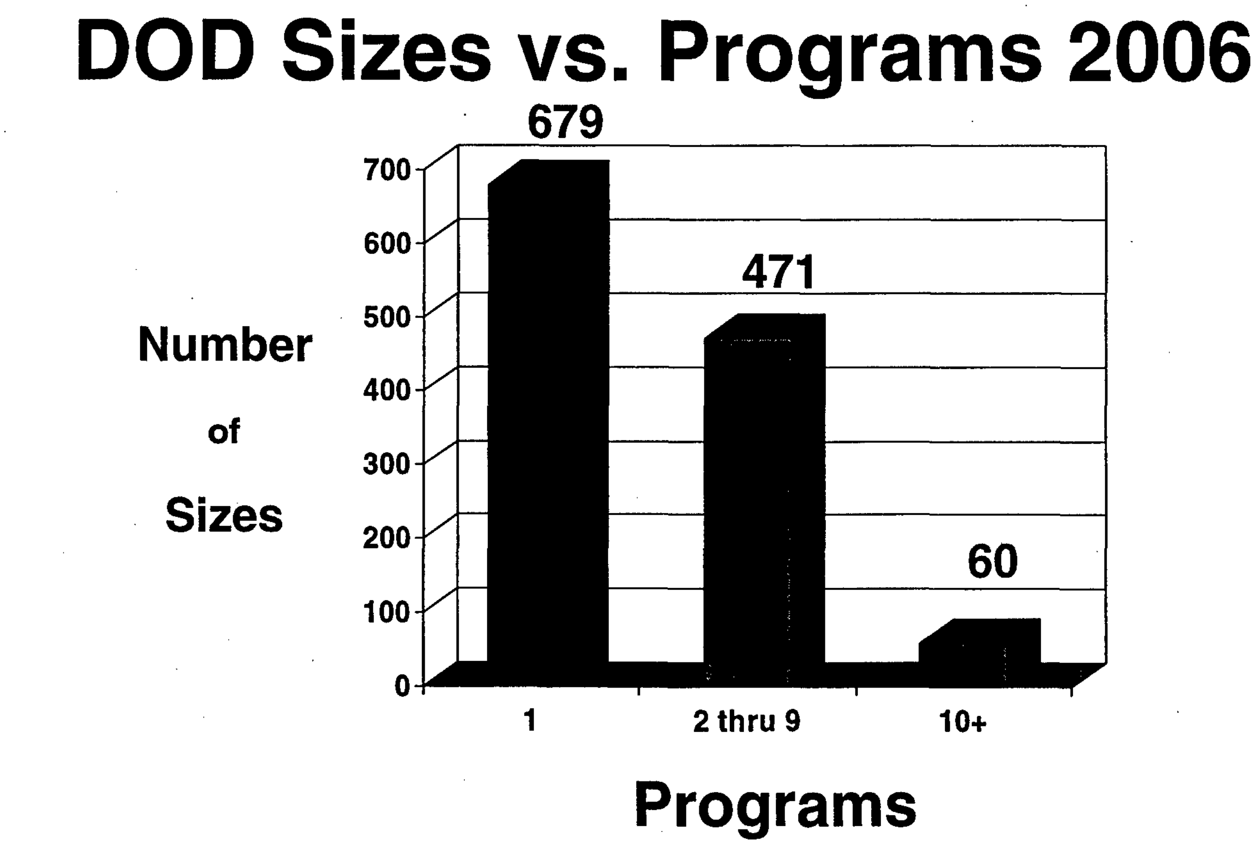

Figure 1. Distribution of 1,210 display sizes across weapon system platforms. Most sizes are unique to a single platform.

6.2 Size Categories as a Percent of DOD Market Share

The some [redacted] display types currently in use can be rank ordered and analyzed by size categories across all DOD platforms. Compared with total displays, one can readily appreciate what percent of the DOD market a given display size occupies..

Table 1 presents display categories in terms of market share. The 29 sizes having the largest percentage of the DOD market are included. The 2.5 x 1.25 in. active area, for instance, represents 13.9% of total DOD displays (99.99% are LCD). The 1.905 x 0.725 in. size represents 12.4% (100% are LCD). The 34° FOV displays represents 11.8% of total DOD displays (97.4% are P-43 NVG phosphor). The 1.949 x 0.534 in. size represents 8.0% (100% LCD). The 40° FOV displays account for 5.7% (100% NVG Phosphor). The 1.680 x 0.390 in. size represents 4.4% (100% LED), while the 2.75 x 1.25 in. weighs in at 2.6% (100% LCD).

The 0.8125 x 0.28125 in. size accounts for 2.3% (100% LED: this was the most quantitative in 2002), the 10.4 in. diagonal for 2.0% (99.7% AMLCD) and the 2.112 x 0.616 in. for 1.8% (100% LCD).

From the Table below it is clear the highest volume direct-view display devices incorporate some form of flat panel technology (LCD, dLCD, LED, AMLCD), while the highest volume virtual-view displays (HMDs, NVGs) still utilize CRT or phosphor technology. The top two most quantitative sizes are used for low-information content displays relative the Precision Lightweight GPS Receiver and the SINCGARS radio, used by all Services..

Table 1 also shows display sizes by quantity, the number of DOD programs using the given display size and the implementation technology or technologies.

Table I. Most Quantitative DOD Display Sizes (Top 29)

Display Size	#Displays	Share*	#WSP*	Breakout by Technology
2.5 x 1.25 in.	158,000	13.9%	17	99.99% LCD, 0.01% dLCD
1.905 x 0.725 in.	141,185	12.4%	21	100% LCD
34° FOV	133,947	11.8%	19	97.4% P-43 NVG Phosphor, 2.6% CRT
1.949 x 0.534 in.	90,738	8.0%	36	100% LCD
40° FOV	64,846	5.7%	22	100% NVG Phosphor
1.680 x 0.390 in.	50,155	4.4%	2	100% LED
2.75 x 1.25 in.	30,000	2.6%	2	100% LCD
0.8125 x 0.28125 in.	26,496	2.3%	2	100% LED
10.4 in. diagonal	[redacted]	2.0%	[redacted]	99.7% AMLCD, 0.3% LCD
2.112 x 0.616 in.	20,356	1.8%	8	100% LCD
13.3 in. diagonal	12,500	1.1%	10	100% AMLCD
2.3116 x 1.6964 in.	11,962	1.1%	3	100% LCD
9.4 in. diagonal	11,642	1.0%	7	51.4% AMLCD, 43.5% LCD, 5.3% dLCD, 2.6% CRT
5.0 x 5.0 in.	11,518	1.0%	50	93% CRT, 7% EM
8.4 in. diagonal	11,108	1.0%	14	100% AMLCD
12.1 in. diagonal	[redacted]	0.9%	[redacted]	100% AMLCD
2.25 x 2.25 in.	10,0[redacted]	0.9%	2[redacted]	99.5% AMLCD, 0.5% EM
19.0 in. diagonal	7,[redacted]	0.7%	4[redacted]	100% CRT
2.75 in. diameter	7,602	0.7%	36	99.0% CRT, 1.0% EM
5.8 x 9.0 in.	7,000	0.6%	1	100% AMLCD
14.0 in. diagonal	6,[redacted]	0.6%	20	99.6% CRT, 0.4% AMLCD
6.0 in. diagonal	6,168	0.5%	1	100% LCD
3.96 x 3.96 in.	5,960	0.6%	12	100% AMLCD
6.0 x 8.0 in.	5,830	0.5%	2[redacted]	100% AMLCD
0.968 in. diagonal	5,436	0.5%	5	100% AMLCD
4.22 x 4.22 in.	5,245	0.5%	22	100% AMLCD
0.62 in. diagonal	5,245	0.5%	1	100% AMOLED
2.8 x 1.2 in.	5,041	0.4%	1	100% AMLCD
20 in. diagonal	4,739	0.4%	18	100% CRT
Subtotal (Top 29)	88[redacted]	78.4%	Total Displays: 1,13[redacted]	

* WSP: Weapon system platform ("platform" can be a dismounted soldier)

6.3 Size Clusters

Size clustering may represent an opportunity for the reduction of the logistics tail. Some 9[redacted] display sizes from among the total 1,2[redacted] have been identified as candidates for clustering based their exhibiting one of three attributes: sizes having quantities greater than 5,000 units (28); sizes used by 10 or more platforms ([redacted]); or a size having a program-quantity index greater than 5,000 (23).[1] The program-quantity index is a quantity defined here as the number of a given size times the number of platforms using it. The cluster ranges are not necessarily symmetric.

Two size cluster points are examined here: 10.4 in. and 19.0 in. These two display sizes are among the most popular in cockpits and crew stations.

The 10.4-in. cluster range is here defined to be 10.2 in. to 10.53 in. diagonal, or 8.15 x 6.10 in. to 8.4 x 6.35 in. (conversely, 6.10 x 8.15 in. to 6.35 x 8.4 in.). These ranges are based on the recognition that 10.4 in. diagonal, at 3:4 aspect ratio, is 8.3 x 6.2 in. and is bounded by cluster candidates 8.0 x 6.0 in. and 8.4 x 6.35 in. The mid-point between these bounds establishes the range about 10.4 in. diagonal. Analysis shows there are 19 existing sizes within this range, encompassing 29,347 displays across 101 programs.

The 19.0-in. cluster range is here defined to be 18.55 to 19.50 in. diagonal, or 12.145 x 16.19 in. to 12.767 x 17.019 in. (conversely, 16.19 x 12.145 in. to 17.019 x 12.767 in.). These ranges are based on the recognition that 19.0 in. diagonal, at 3:4 aspect ratio, is 12.44 x 16.58 in. and is bounded by cluster candidates 18.1 in. diagonal and 20.0 in. diagonal (or 11.85 x 15.80 in. and 12.44 x 16.58 in., respectively). The mid-point between these bounds establishes the given range and encompasses 12 existing sizes and 8,888 displays across 96 programs.

These two size clusters alone may represent an opportunity to consolidate 31 sizes into 2 sizes across 197 different programs as summarized in Table II.

Table II. Candidate Ranges for Size Consolidation.

Size Range	No. Sizes	No. Displays	No. Programs
10.4 +0.13/-0.20 in.	19	29,347	101
19.0 +0.50/-0.45 in.	12	8,888	96
Totals	31	38,235	197

6.4 Technologies

Defense displays documented in our study entail as many as 17 different technologies. These encompass the range of older technologies such as cathode ray tube (CRT), night vision goggle (NVG) and thermal sight phosphors, electromechanical (EM) and incandescent, to the more exotic such as Liquid Crystal on Silicon (LCOS) and Biaxial Scanning Mirror-Microelectromechanical System. In between are the many forms of flat panel technologies that have come to the fore since the 1980's and 90's: dichroic and passive matrix Liquid Crystal Displays (dLCD, LCD, respectively), active matrix LCD (AMLCD), thick and thin film electroluminescent (EL), plasma, inorganic and organic light emitting diode (ILED, OLED, respectively), etc. Note that CRT, EM and incandescent technologies account for some 14.7% of the existing DOD market. NVG and thermal sight phosphors add another 17.5%. By contrast, flat panel technologies account for as much as 68.4% of the DOD market, with the liquid crystal class, alone, being 56.3%. The numerical break-out by technology for DOD displays, both direct- and virtual-view, is tabulated in Table III and illustrated in Figures 2 and 3. To date, there has been no comprehensive effort made to gather information on electro-mechanical and incandescent displays. Typically, for cockpits, electro-mechanical ADIs and HSIs are documented only when there are no fully electronic primary flight instruments.

[1] [redacted] sizes share the common attribute of having quantities greater than 5,000 units and utilization by 10 or more programs.

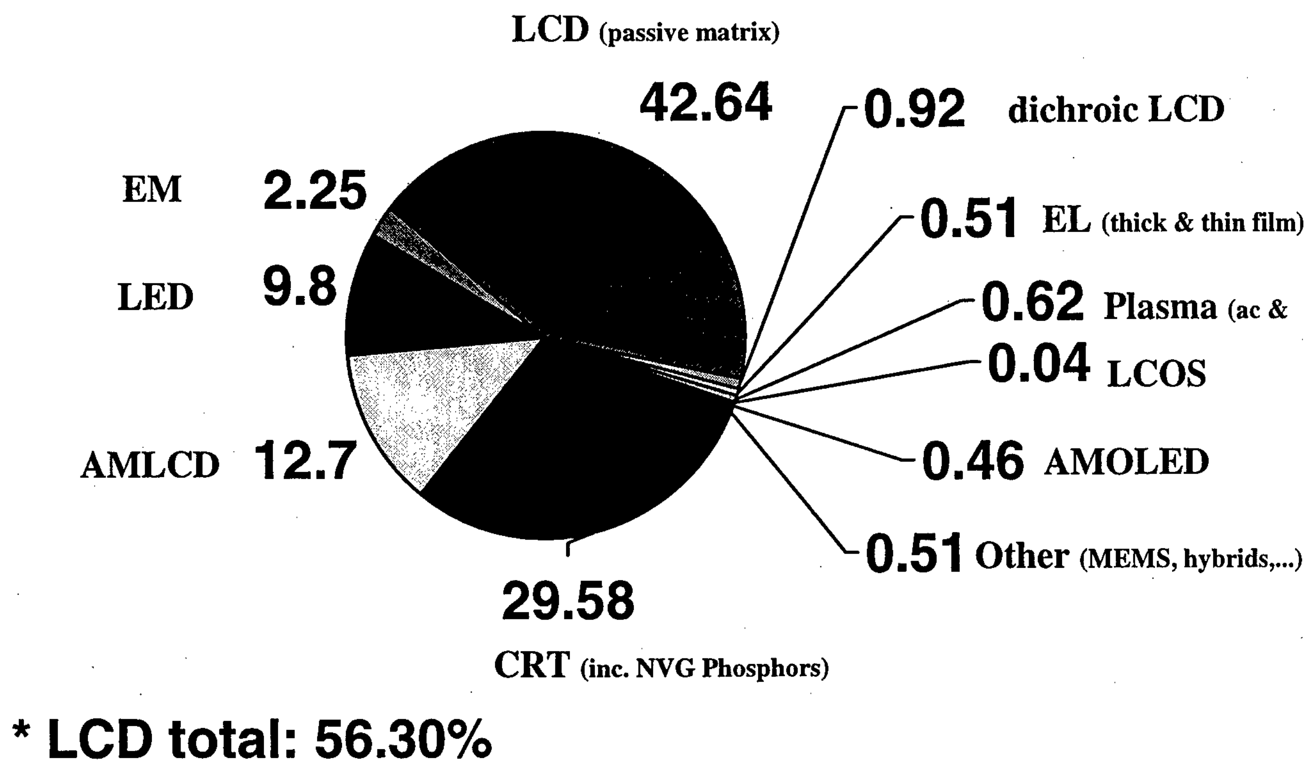

Figure 2. Pie chart showing major DOD display technologies by percentage.

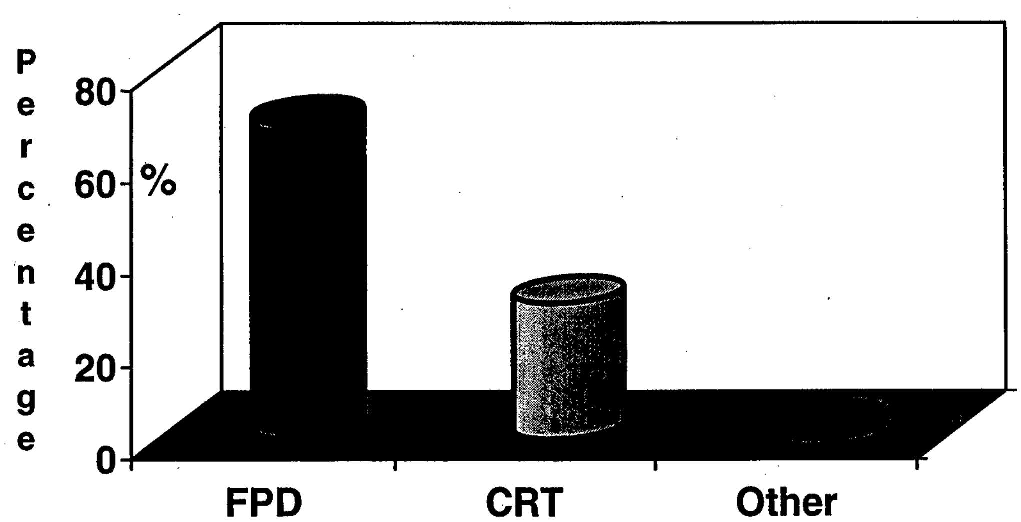

Figure 3. Penetration of Flat Panel Display Technology into Defense Applications.

Table III. Defense Display Market by Technology

Number	Percent	Technology
483,7[redacted]	42.64 %	Liquid crystal display (LCD, note: passive matrix; no TFTs in pixels)
198,342	17.48%	NVG & Thermal Sight Phosphors (P-43, P-53, InGaAs, InSb, etc.)
[redacted]	12.66 %	Active matrix liquid crystal display (AMLCD, note: TFTs in each pixel)
137,[redacted]	12.10%	Cathode ray tube (CRT), inc. 0.72% HUD and 1.61% Helmet CRTs
111,2[redacted]	9.80 %	Inorganic light emitting diode (ILED, note: LED often used for ILED),
25,[redacted]	2.25 %	Electro-mechanical (EM)
10,3[redacted]	0.92 %	Dichroic LCD (dLCD, note: dichroic LC material decomposes in sun)
7,046	0.62 %	Gas discharge plasma (Plasma, AC or DC discharge maintainance)
5,245	0.46 %	Miniature Active matrix organic light emitting diode (mini-AMOLED)
4,141	0.36%	Incandescent
3,644	0.32 %	Thin-film inorganic electroluminescent display (TFEL)
2,189	0.19 %	Thick film electroluminescent (EL)
621	0.05 %	Digital Micromirror Device-Microelectromechanical System (DMD, aka Digital Light Processing, or reflective active matrix micromechanical display on silicon substrate)
481	0.04%	Liquid crystal on silicon (LCOS, reflective miniature AMLCD on Si subs)
314	0.03 %	Unknown
250	0.02 %	Hybrid CRT/LCD
250	0.02 %	Hybrid: EM/LED
100	0.01%	Biaxial Scanning Mirror-Microelectromechanical System
1,13[redacted]	100.00 %	TOTAL

6.5 "Low" Versus "High" Information Content and Design Class.

There is an important distinction to be made between displays capable of "high" information content versus "low." One aspect of this distinction is based on the total number of pixels. Number of pixels determines the instantaneous information density the viewer sees in one frame. We here define any display having less than quarter-VGA (>76,800 pixels) as having "low" information content (LIC). By contrast, any display capable of quarter-VGA or greater is defined as having "high" information content (HIC). In addition, we also look at whether the display demonstrates video capability, i.e., has pixel addressing capability characterized by frame and refresh rates. We here define any display having frame or refresh rates as possessing "high" information content. Indeed, the specified criteria appears to be mutually exclusive. Our analysis so far reveals there are no DOD displays with less than quarter-VGA having video capability. A comparison of LIC and HIC for all platform groups is provided in Table IV. Note that in many instances the basic criteria is unknown, i.e., these are displays for which resolution and frame/refresh data are unavailable.

Aside from information content, Table IV also addresses design class. Design class regards the manner by which displays come into existence through research and development (R&D) funding, and what market the finished product is designed for. "Custom" refers to a product for which R&D dollars were paid by U.S. government and for which the intended market was the U.S. military. Nevertheless, the product might eventually be leveraged for dual use by the civil market, e.g., a military avionics display repackaged and sold to the civil aviation community. "Commercial-Off-The-Shelf" (COTS) on the other hand refers to a product for which R&D was wholly funded by private industry and for which the initially intended market was civil (consumer-grade laptops, notebook computers, etc.). Thanks to the 1992 Perry initiative, these can, and have, found their way over time into the military market, as witness Navy surface vessels and command and control centers. "Ruggedized" COTS refers to remanufacturing commercial grade display products to meet more demanding military applications in terms of temperature, altitude, shock and vibration extremes, to include electromagnetic pulse and nuclear, biological and chemical hardening. In all such cases, government pays the penalty cost for the upgrade. Ruggedized COTS, therefore, entails a product for which R&D was funded by private industry, with design focused on satisfying a civil application, but where remanufacturing was funded by government for use by a military customer.

Aside from identifying "LIC" and "HIC," Table IV provides a general description regarding whether displays for a given DOD platform group are typically Custom, COTS, Ruggedized-COTS, or a combination of these.

Table IV. Analysis of Aircraft Cockpit Military Display Market Segment.

Category	Platforms	Sizes	Displays	LIC	HIC	Unk	Design Class
Defense-wide	[redacted]29	[redacted]	[redacted]339	[redacted]690	137,403	983,246	Custom&Ruggedized COTS
Aircraft cockpits	317	416	208,590	11,950	36,979	160,743	Custom-design
Type of Aircraft Cockpit							
Fighter/attack	[redacted]	[redacted]	[redacted]1,025	680	12,080	28,265	Custom*
Bomber	[redacted]	[redacted]	[redacted]	0	973	1,204	Custom*, some Rugged COTS
Helicopter	[redacted]	88	68,440	3,261	10,049	55,130	Custom
Sensor /surveillance	[redacted]	100	11,072	252	2,027	8,793	Custom, but by civil aviation mfr.
Cargo/tanker	[redacted]1	128	62,623	4,817	9,927	47,879	Custom, but by civil aviation mfr.
Trainer	[redacted]	42	23,253	2,940	1,741	18,572	Custom
[redacted]							
Other							
Land Vehicles	[redacted]	[redacted]	87,923	588	21,805	65,530	RCOTS
Portable (Dismounted)	[redacted]	[redacted]	[redacted]641	33,071	51,959	495,611	[redacted]
[redacted]							
Maintenance Equipment	[redacted]		[redacted]	[redacted]	[redacted]	340	[redacted]
Head/Helmet Mounted	[redacted]		[redacted]		6,218	195,171	[redacted]
[redacted]							
Water Surface Vessels	[redacted]	[redacted]	71,646	81	17,751	53,814	[redacted] Custom
Unmanned Vehicle	[redacted]	[redacted]	[redacted]	0	727	20	[redacted]
Command/Control	[redacted]	[redacted]	[redacted]71	0	171	1,400	[redacted] Custom

Note: Data on display quantities and information content determined via ACCESS analysis.[5]

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 The Future DOD Market

The DOD display market will continue to grow over the coming years. Already our 2006 report reveals over two and one-half times as many fielded and contracted displays as were identified in 2002: 1,134,800 versus 438,800. These higher numbers are due not only to the fact we have covered a broader range of the DOD market already existing in 2002 but because older fleets are expanding, e.g., C-17, V-22, C-130J, and new fleets are coming on board, viz., Stryker, DD (X) destroyer, Global Hawk. Also, newer technologies are continually replacing the old. The present inventory of some 1,134,800 displays will be largely replaced over the next 15 years. Given the dwindling industrial base for CRT and EM technologies, together with the ever-increasing sustainment cost for these older technologies, it can be expected that all current DOD inventory relative CRT and EM will require near-term technology upgrade via form-fit-function or instrument panel re-design programs. This represents 32% of the existing DOD market, or some 362,000 displays. In the out-years, however, currently installed FPDs will require upgrade in order to leverage anticipated improvements.

Most technology insertion opportunities will be for AMLCDs. However, many emerging technologies, such as AMOLED, Digital Micromirror Devices (DMD), Biaxial Scanning Mirror-Microelectromechanical Systems and Liquid Crystal on Silicon (LCOS) displays, may be used by future programs. Indeed, we have witnessed bridgeheads established by some of these technologies already, e.g., LCOS for the FA-22A Primary Multi-Function Display, and DMD for the E-3B/C Common Large Area Display Set.

7.2 The Potential for DOD Display Commonality

Our study shows significant opportunities to increase commonality across DOD programs.

Understandably, existing cockpit and mission crewstation configurations impose a mechanical engineering limitation to the latitude any one program has in terms of display size conversion. While not so much a problem for surface ships or command and control centers, this limitation is particularly severe for fixed and rotary-wing cockpits, where there is no room for expansion, and changes to console real-estate come at a premium. Beyond form-fit-drop-in, even slight changes in physical display size impose hundreds of millions of dollars worth of system-level, non-recurring engineering (NRE) costs. Even so, multiple programs pursuing joint acquisitions of common displays may indeed augur over-all cost savings, not to mention savings for the logistics support community once fielded.

Table 1 shows the majority of existing DOD display sizes, even now, are unique to a single program: 679 out of 1,210 display sizes fit this category. This suggests most DOD program offices remain aloof when it comes to understanding what is already utilized to meet similar requirements, persuaded by their contractors their needs are unique. The "Military display market" technical report, fourth comprehensive edition, is a tool by which DOD program offices can do their homework and understand what sister programs across the Services are already doing to satisfy similar mission requirements. Clearly, there are opportunities for synergy, and DOD program offices should consider this situation in pursuing both new system developments and upgrade of existing capabilities. Achieving commonality would obviously mean fewer upgrades that are purely form-fit-function. Also, program managers would need to find ways to cooperate across programs and across services.

Cross-program investment strategies are needed. Program managers may want to cooperate, but program budgets and schedules force them to "go it alone." The result is a continuing plethora of display sizes and costly logistics pipelines. Existing efforts such as Air Force's Aging Aircraft SPO common avionics program or NAVAIR's common enterprise display system working group, need to be expanded to become cross-service efforts. But concern for cockpit avionics is not the only area needing emphasis. Mission crewstations for C4ISR is another. There is certainly a commonality opportunity for the Navy UYQ-70 workstation program (carriers, cruisers, Aegis, submarines, E-2C), and Army's Common Hardware Software program (mobile ground command and control components). And these may be joined to form a tri-Service connection via the Air Force Common Large Area Display Program (CLADS) involving AWACS.

8. DISCUSSION

Key aspects of eight (8) U.S. Navy, Army, Marine and Air Force programs are provided.

8.1 Joint Strike Fighter (F-35)

As of September 2005, Lockheed Martin de-selected Rockwell Collins Kaiser and instead selected L-3 Communications Display Systems (L3DS), Alpharetta GA, to go forward with a Panoramic Cockpit Display (PCD) for the F-35. This means a technology switch from Liquid Crystal On Silicon (LCOS) to AMLCD. The L-3 plan is to use a 20 x 8 in. AMLCD (without moulian) with 2560 x 1024 pixel resolution (per the previous design), with separate addressing of each screen half for redundancy. The display glass is to be provided by LG-Philips.[8] Preliminary Design Review was held in 2005 and no further details are available at this time. However, plans are still in force for the "Ruggedized CyberDisplay 1280," the first-ever AMLCD approach for an avionics Helmet Mounted Display (HMD) as part of a new program deliverable. The helmet display is monochrome binocular and features two Kopin SXGA (1024 x 1280) AMLCDs w/Heater, one each per optical path, with an overall field of view of 52° x 30° (W x H).[9] Further characteristics include an active area of 0.760 x 0.610 in. (W x H, 0.968 in. diagonal), pixel size of 15 micrometer, pixel fill factor of 47%, data refresh of 60 Hz, 8-bit (256 level) gray scale, >5.66:1 contrast ratio for a design luminance of 750 fL, with minimum luminance set at 0.04 fL (with a goal of 0.01 fL), a +/- 25° horizontal and +/- 15° vertical viewing angle (40° FOV), a maximum altitude (operating) of >50,000 feet, shock and vibration limits greater than RAH-66 HIDSS, color shift radius of black<0.05; white<0.02 (1976 CIE parameters), green color chromaticity coordinates u' = 0.070, v' = 0.560, specular reflectance < 5%, diffuse reflectance < 6% and an operating temperature range between –35 to 70°C and a storage range between -55° to +99°C.[10] [Additional F-35 displays include an off-the-shelf Standby Flight Display (approx. 3 x 5 in.) similar to the X-35, F-16 and C-130, selected in FY03, and an off-board Maintenance Interface Panel (possibly a laptop) for logistics support, to be selected by Block 3.[11]]

8.2 PC 11 USS Whirlwind (PC 1 Cyclone class)

USS Whirlwind is one of the Cyclone class of coastal patrol boats serving with the US Navy. The Cyclone class is based on the British Ramadan (Vosper Thornycroft) design, but is heavily modified for USN requirements. Intended for use with Special Operations transport and support, they are primarily used for patrol and drug enforcement duties. All 13 boats of the fleet, delivered between 1993-1996, are similarly configured. Most of the display equipment is commercial grade, unless otherwise specified. The some 52 CRT-based General PC displays, measuring 16.0 in. diagonal, are Sceptre Plug and Play "Low Radiation" VGA resolution with full color, while an equivalent number Dell laptops, with AMLCD color monitors, were funded as future replacements. Existing units, when inadvertently dropped on deck, do not hold up well to rough-handling; still, the follow-on units are to remain commercial grade. The Radar Display is implemented via a Sperry Rascar 2500M monochrome, touch screen display. The IC-M120 is a VHF Marine Transceiver by ICOM with seven-segment type monochrome display. The SRD-331 Master Display Unit is monochrome. The Situation Display is for the Voyage Management System; with color touch screen and SVGA resolution. A software upgrade will allow separate dimming between one part of the display and its FLIR image overlay. The International Maritime Satellite Control Head (IMSCH) is implemented via a Magnavox "Magna Phone M" monochrome (black on grey-green) display. The Raynav 780 LORAN C Navigator is a land-based Global (GPS) Positioning System with monochrome display. The Raystar 920 satellite-based GPS uses a monochrome display. The AN/PSN-11(V)1 Navigation Set, Satellite Signals, is a military specification portable device by Rockwell Collins, with a monochrome image area of 2.4375 x 1.1875 in. The VHF Spectra Radio display by Motorola is monochrome. The Tactical Action Officer (TAO) console uses an 18.375 in. diagonal color display with SVGA resolution by Sperry. The BMS-1000 has the same Sperry display as the TAO, while the computer software allows for more options. The Sonar display, with 13.1875 in. diagonal active area, supports the Wesmar series 3000 sonar set with a ViewSonic E641 color monitor. The Forward-Looking Infra-Red display is monochrome. The TeleNav display, which allows for overlay of latitude and longitude information over FLIR imagery, uses a monochrome display. The AN/APR-39 is a military specification Early Warning Threat Device, with 2.689 in. diameter monochrome display. The Fathometer display uses large seven-segments per character for four characters in monochrome. The SRD-331 Remote Display unit by Sperry uses a monochrome display. The Weatherpak System windspeed indicator is a monochrome display. The 8 millimeter Recorder Display is part of a Sony GVA 500, with full color. The Communications Laptop, a Toshiba Satellite 330 CDT, has a color display. The CGS-100 display for the communications computer, incorporates SVGA color. The USC-54(V) Receiver-Transmitter has a monochrome yellow display. The BR-700 Receiver display is comprised of six characters, each of 7 x 4 pixels in monochrome red. The UD-700 Demultiplexer has a monochrome display. The RT-1523 VHF Transceiver is a military spec. device with monochrome green display by Nemonics, Inc. The KYV-5 Crypto device is military spec. with two characters comprised of 4 x 7 pixels in monochrome red. The KG-84C by Bendix is military spec., with two characters of 4 x 7 pixels per character in monochrome red. The KWR-46 Crypto device is a military spec. display having eight characters, with 5 x 7 pixels per character. The VRC-83 by Harris is military spec. with a display having monochrome, blue-green, seven-segment characters. The CYZ-1A by Motorola is a military specification unit with a display window comprised of seven-segment black on silver characters. The LST-5 by Motorola is a military spec. unit with a display similar in appearance to the CYZ-1A. The RF-1522R/T(E) by Harris is a military spec. device, with a display having two rows of 16 characters each, each character composed of 5 x 7 pixels black on green.[12] In all, there are some 50 electronic displays per ship, approximately half with active area screen sizes < 2.25 x 2.25 in.[13]

8.3 "Stryker"

The Stryker fulfills an immediate requirement in the Army's current transformation process to equip a strategically deployable (C-17/C-5) and operationally deployable (C-130) brigade capable of rapid movement anywhere on the globe in a combat ready configuration. The "Stryker," otherwise known as the "Interim Armored Vehicle," is comprised of ten different vehicles of two variants, the Infantry Carrier Vehicle, of which there are nine configurations, and the Mobile Gun System, of which there is one configuration. Early in the program, General Motors was the prime for the Infantry Carrier Vehicle, Command Vehicle, Engineer Vehicle, Anti-Tank Guided Missile Vehicle, Future Scout Vehicle and the Reconnaissance Vehicle, while General Dynamics was the prime for the Mobile Gun System, Medical Evacuation Vehicle, Mortar Carrier and Nuclear, Biological, Chemical (NBC) Vehicle. More recently, General Dynamics Land Systems became sole prime for all configurations. By September 2005, there was a total projected requirement for 2,548 vehicles, with contracts in place for Brigades 1 – 4, totaling 2,031 vehicles.[14] All configurations of Stryker are comprised of the Squad Leader's Display (SLD), Driver's Viewer Enhancer (DVE), FBCB2 display, M88 Detector display, VDR-2, Enhanced Position Location Reporting System (EPLRS) display and the RT-1523E Single Channel Ground and Airborne Radio System (SINCGARS). Additionally, a Remote Weapons Display (RWD) is found on the NBC, Mortar, Recce, Engineer and Command Vehicle. Details for DVE, FBCB2 and RT-1523E can be found in previous

papers. Squad Leader's Display parameters are detailed elsewhere in this paper. Details on the VDR-2 and M88 Detector have not yet been documented. The Remote Weapons Display is manufactured by Kongsberg, with ruggedized display glass from White Electronics. The display technology is amorphous thin film transistor LCD, with 211.2 x 158.4 mm image area and an overall module size of 246.5 x 179.4 x 11 mm (WxHxL) face. The display has 640 x 480 (VGA) resolution, with 261,144 colors and 64 gray levels. Maximum luminance is 200 nits (58.38 fL). Contrast ratio at optimum viewing angle for dark ambient is 300:1. Horizontal viewing angle is ±45°, ±30° vertical. The 1936 CIE color coordinates for white are: x = 0.313, y = 0.329. The module withstands a shock of 40g, 6-9 ms duration. Vibration tolerance is qualified according to MIL-STD-810, method 514.4.[15]

8.4 U.S. Space Command Global Satcom Support Center (USAF), Peterson AFB

The HQ US Space Command Space Operations Center and Global Satcom Support Center are both located within Bldg 1470 at Peterson AFB. All electronic displays for both centers are COTS; all have color capability and a minimum of 1024 x 768 resolution, although some screens are intentionally operated at 800 x 600. These centers operate 24 hours a day, seven days a week and the displays are in continuous use. Over the past 3.66 years there have been no maintenance or availability issues, although the Information Systems Security Officer has stated flat panels are desirable as an upgrade in order to optimize available surface area. Furthermore, it is desirable that at least some monitors be electro-magnetic pulse hardened. Acronym definitions and brands, where known, follow: The 9 in. Close Circuit TVs are JVC TM-9U and Sanyo VM4509, the latter being monochrome, as is the 11 in. by Phillips. The Information Display Terminal is an "Enhanced VGA" Magnovox. The Process Display System Migration (PDSM) is a NEC Multisync XtraView LCD 2010. The C2AS NORAD is a Hansol E17CE. The Global Command and Control System (GCCS) 19.75 in. is by SUN. The Officer In Charge (OIC) display is a Hansol E17CL; the "-K" is a Gateway FPD1500; the "Position 3" is a Hansol 900P; and the GSSC NIPRNet is a Panasonic P17. The Information Display System (IDS) is part of a laptop manufactured by Pavillion. The Space Operations Center (SPOC) Web Server monitors are DELL. The Autodin Message Distribution Terminal (AMDT) is by TOUCH. The Enhanced Command Console (ECC) is a NEC MultiSync LCD 400V, with Raytheon as integrator. The C2AS-US is implemented variably with NEC MultiSync LCD 1810 XtraView monitors, Hansol 710As, Panasonic P17s, MultiScan 200ES, Samsung SyncMaster 700s, DELLs, Panasonic CF-47 laptops or Sony MultiSync 200ES. The Non-Classified Internet Protocol Network (NIPRNet) is a NEC LCD 400V, another a Panasonic P17, while the 10 laptops, Gateway Solo 2500s, are used for contingencies. The NORAD US Space Command Intelligence System (NUIS) displays comprise an Art Media, three are SUNs, and a Power Lite PR1024-24 laptop. The Command and Control Processing Display System (CCPDS) "-2" is monochrome, a Digital VT320. The Space Battle Management Core System (SBMCS) CRT is a DELL M570, while the laptops are DELL 7000 and 7500. The Terrestrial Critical Control Circuit (TCCC) is a DELL 1503FP. The Red, Green, Blue (RGB) monitors; both 27.5 in. displays, are NEC XP29 MultiSyncs. The Crisis Action Team and Battle Staff (Crisis AT&BS) displays are Panasonic CF-47 Toughbook laptops costing $6000 per, and meant for austere relocation to Cheyenne Mt. The Multi-Purpose Video Display Monitors (MPVDM) are implemented with Sony Trinitrons. The Video Cassette Player (Trainer) is instantiated by a Philips Magnavox CCZ092AT01.[16]

8.5 Predator Common Ground Control Station

The Common Ground Control Station for Predator Un-Manned Aerial Vehicle (UAV) is developed by General Atomics Aeronautical Systems, San Diego CA, which is also prime contractor for the UAV itself. The some 40 Predators in service are assigned to the 11th and 15th Reconnaissance Squadrons at Nellis AFB, with a required ratio of one control station per four UAVs. Each control station is comprised as follows: three (3) 19 in. CRT Tracker Displays made by Barco (model RDG-651), with ±80° viewing angle in both the vertical and horizontal axes, 16.7M colors, 1280 x 1024 resolution, 47-94 kHz frame rate, 40–120 Hz refresh rate and 130 cd/m^2 maximum luminance; three (3) 19 in. CRT Head-Up Displays (HUD), the same Barco model number and characteristics as per the Tracker display; two (2) 19 in. CRT Data Exploitation Mission Planning and Communication System (DEMPC) displays, again, with same Barco model number and same characteristics as the HUD; one (1) 27 in. CRT Synthetic Aperture Radar (SAR) display, also made by Barco, model number MX-2500, with the same viewing angle and number of colors as the Tracker Display, but with 2048 x 2048 pixel resolution, 126.8 kHz frame rate, and 56-83 Hz refresh rate; six (6) 10.4 in. LCD Head Down Displays (HDD), vended by CTX Opto Electronics, model number PV540M, with viewing angle ±45° horizontal, ±25° vertical, 262K colors, 640 x 480 resolution, 24-38kHz frame rate, 56-75 Hz refresh rate and 150 cd/m^2; one (1) 14 in. LCD Auxiliary Mission Monitor, by View Sonic, model # VP140, has a ±75° horizontal and ±63° vertical viewing angle, 16.7M colors, 1024 x 768 resolution, 30-60 KHz frame rate, 50-75 Hz refresh rate and 200 cd/m^2 maximum luminance; one 15 in. LCD Mission Monitor, also by Viewsonic, model # VP150, has the same viewing angles, same number of colors and same resolution as the auxiliary unit, but 24-61 kHz frame rate, 50-77 Hz refresh and a maximum luminance of 250 cd/m^2.[17] Additionally, there is one (1) Rockwell Collins AN/ARC-210(V) radio, with control-display head C-11898A, with

dichroic LCD active area measuring 2.2 x 0.70, with 2.708 x 1.056 in. outer bezel. The AN/ARC-210(V) has 12:1 day and 4.5:1 night contrast ratio, 0.5 – 1.5 fL output brightness and NVIS Green A compatibility.[18] Aside from the 10 GCS units delivered to USAF, General Atomics Aeronautical Systems retains one for in-house use.[19]

8.6 MH-60R LAMPS Block II Upgrade

The MH-60R is an SH-60B or -F that has undergone a "remanufacturing" process. In all, approximately 243 SH-60B and SH-60F helicopters currently in the fleet are to be remanufactured as MH-60Rs over 10 years. The contract, valued at roughly $2.5 billion to Lockheed Martin Federal Systems, involves modifying the airframe, as well as the avionics systems. Avionics upgrades will make the Hawkeye more Network Centric Warfare capable. Upgrades are aimed at optimizing the Hawkeye for littoral operations. The modifications being effected are substantial. Aside from changes to the airframe, the new glass common cockpit (which it will share with the MH-60S, CSAR-X and VH-71) will help reduce logistics and life-cycle costs. Major upgrades will occur to both flight and mission avionics, to include upgraded Mission and Flight Displays. The new flight displays include two Northrop Grumman (pka Litton) 12.1 in. diagonal color Smart Multi-Function Displays (SMFD) with commercial glass by Hydis (S/N A00026), ruggedized by Panelview. These displays will have a hard silicone front and back, and will be qualified according to military standard procedures. LMCO plans to be an alternate source for these same displays. Resolution is XGA (1024 x 768) with a day mode white luminance greater than 350 fL at normal viewing angle (the specification calls for 350 fL, minimum), and greater than 200 fL at ±45° horizontal and +30°, -10° vertical (the specification calls for 180 fL @ +/- 30° horizontal, 0° vertical and 0° horizontal, 20° vertical). Contrast ratio is 6:1 at 8,000 fc diffuse and 2,000 fL specular. Low ambient contrast ratio, on-axis (0°H, 0°V) is approx. 250:1, while best case is greater than 350:1 @ 0°H, 10°V. Dimming is 7,000:1, or from 0.05 fL to the required maximum. Chromaticity measurements across the display surface @ 0°H, 0°V are as follows:

Color	u'	v'
Red	0.408	0.525
Green	0.188	0.550
Blue	0.075	0.370
White	0.225	0.515[20]

There will be three "Dumb" MFDs (Video Monitors), one for the cockpit pilot mission, co-pilot mission, and sensor operator workstation in the cabin.[21] The Smart MFDs and "Dumb" MFDs are essentially the same units although the bezels are slightly different. The bezel-to-bezel measurement is 12.06 x 9.40 in., the console cutout is 11.10 x 8.705 in., (instrument body behind the bezel is 11.07 in. wide) while the back of the instrument measures 10.03 x 8.0 in. .[22] There will also be one CMA-730 Vertical Instrument Display provided by CMC Electronics, also found on the SH-60, OH-58, AH-64 and E-2C. It has a brightness of 100 fL, 10:1 contrast ratio, >80° viewing angle and boasts "color."[23]

8.7 SINCGARS Radio, ITT Model RT-1523E

The Single Channel Ground and Airborne Radio System (SINCGARS) Army program management is handled by CECOM, PM Tactical Radio. Production delivery is split between General Dynamics Land Systems (models 1523A and 1523D) and ITT. The ITT E variant (there are also RT-1439, RT-1523, RT-1523B, RT-1523C and RT-1476 variants) uses the Grayhill A3266120-1 ASIP Version LCD display sub-assembly, of which Grayhill has furnished 59,648 units. Varitronix manufactures the LCD glass, while Grayhill is responsible for ruggedizing. The other supplier is CMC, Montreal, Quebec, which provided the same specification display sub-assemblies, including 1.949 x 0.534 in. active area size, as per Grayhill.[24] The screen displays characters only, in monochrome, with no gray levels. Maximum brightness is between 0.75 and 2.0 fL. The display provides adequate contrast between characters and background for suitable legibility under all lighting conditions between 0 to 30,000 Lux (2,787 fC) when measured orthogonal to the plane of the display. The display features automatic contrast control which is temperature compensated over the operating range of
-51 to +85° C.[25] Total RT-1523E radios delivered to U.S. Army is 81,597 units.

8.8 AN/AVS-7 Aviator's Head-Up Display

The AN/AVS-7 HUD, vended by Elbit Defense Corp., Haifa, Israel, utilizes a red P-56 phosphor CRT with minimum screen size of 11.5 mm. diameter (0.453 in.). Light output is 100fL. Average power consumption is 2 Watts, with an average of 0.25 amps 5

Watts max. The ANVIS configuration includes a neutral density filter attached to the ANVIS objective lens assembly with an average transmission reduction of up to 15% across the ANVIS spectrum. The CRT is ruggedized with "high resolution." The Field Of View of the CRT symbology is 34° +/- 1°. The symbology contrast ratio is specified to be a minimum of 2 at a scene light level equivalent to 0.005 +/- 10% fc. With no light on the scene, the symbology contrast ratio is specified to be ≥ 99. The symbology resolution at the user's eye is specified to be greater than 0.45 cy/mr in both the vertical and horizontal. Symbology luminance uniformity is specified such that for any two widely separated symbols intended to be of the same brightness or any two elements of the same symbol, non-uniformity shall be less than 1.41:1. Total weight of the display unit (DU) shall not exceed 650 +/- 65 grams. The DU has a predicted MTBF of at least 4000 hours when calculated according to MIL-STD-217E. The DU is specified to operate without degradation at exposure levels of up to 95% humidity. It is further specified to operate without degradation when exposed to a steady state acceleration up to 6g for 1 minute, and operate without degradation when subjected to the vibration environment of the various helicopters for which it is intended (e.g., CH-46D/E, CH-47F, HH-60L, etc.). The DU attached to the ANVIS is specified to meet the vibration, temperature and altitude requirements of MIL-A-49425. The operating temperature range for the DU extends from -32° to +52°C and the non-operating range from -35° to +71°C. Operating altitude is 15,000 feet, storage altitude is 50,000 feet.[26] The AN/AVS-7 is a modification to the AN/AVS-6 Aviator's Night Vision Imaging System goggles.

9. ACKNOWLEDGEMENTS

We thank the DOD Program Offices, Logistics Centers, and industrial partners that provided information over the course of this study. Special thanks go to Pat Donovan, Director of Avionics, Boeing St Louis, for timely and comprehensive responses on the C-130 Avionics Modernization Program. Special thanks also go to Jon Neubauer, Systems Engineer, L-3 Communications, Wright-Patterson AFB, for editorial assistance to the technical report on which this paper is based, and the first-ever ACCESS automated data analysis affecting quantitative determinations of low- and high-information content displays.

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[4] D.D. Desjardins and D.G. Hopper, "Updated military display market assessment," *in* ***Cockpit Displays VI: Displays for Defense Applications***, Darrel G. Hopper, Editor, SPIE 3690, pp. 1-24 (1999). This paper is an interim update of work since the March 1998 report; the present paper (published in Cockpit Displays VII in 2000) is the full, FY99 update report.

[5] Data from ACCESS data base provided by Jon Neubauer, Systems Engineer, L-3 Comm, Wright-Patterson AFB OH (937-255-8466) to LtCol Dan Desjardins, AFRL/HECV, WPAFB OH (937-25-4079), 13 January 2006. Additional corrective data provided 15 February 2006.

[8] E-mail from Dr. Darrel G. Hopper, AFRL/HECV (937-255-8822) to LtCol Dan Desjardins, AFRL/HECV (937-255-4079), 3 October 2005. This follows a previous voice-mail indication from Mr. Randall E. Blackburn, Lead, Displays and Cockpit Avionics, Joint Strike Fighter Program, Naval Air Systems Command, Research and Engineering Group, Patuxent River, MD (301-342-9263) earlier in 2005.

[9] Telecon between Mr. Lou Taddeo, Director of Business Development, Vision Systems International, San Jose CA (408-433-

9720, ext. 272) and Maj Dan Desjardins, AFRL/HECV, WPAFB OH (937-255-4079), 7 February 2002.

[10] "Kopin SXGA Performance Summary" provided by Mr. Michael Presz, Vice President and General Manager, Kopin Corporation, Los Gatos CA (831-430-0688) to Maj Dan Desjardins, AFRL/HECV, WPAFB OH (937-255-4079), 8 February 2002. Editorial corrections to update the luminance output from 1650 to 2600 fL, the light transmission from >10% to >12% and the max operating temperature from 51 to 70° C, provided by Mike Presz by e-mail on 11 February 2002. Update and refinement to these parameters provided by Mr. Chu Li, Lead Engineer, F-35 HMD and RAH-66 HIDSS, Rockwell Collins (pka Kaiser Electro-Optics), San Jose CA (408-532-4244), 13 Mar 03. Luminance ranges provided by Mr. Jim Byrd, ASC/ENAS, WPAFB OH (937-255-8731), 19 May 2003.

[11] Telecon between Ms. Donna Potter, Kaiser, San Jose CA (408-532-4179) and Maj Dan Desjardins, AFRL/HECV, Wright-Patterson AFB OH (937-255-4079), 6 February 2002. Also, e-mail from Thomas Frey, Lockheed Martin, 11 February 2002.

[12] Face-to-face between Lt John Krisko, Operations Officer (for Bridge and part of Combat area), Radioman First Class Phil Rivette (for Combat and Radio Room), USS Whirlwind (PC 11), Pier 61, Naval Station Little Creek VA (757-462-5098) and Maj Dan Desjardins, AFRL/HECV, WPAFB OH (937-255-7886), 10 November 1998.

[13] Face-to-face between Lt John Krisko, Operations Officer (for Bridge and part of Combat area), Radioman First Class Phil Rivette (for Combat and Radio Room), USS Whirlwind (PC 11), Pier 61, Naval Station Little Creek VA (757-462-5098) and Maj Dan Desjardins, AFRL/HECV, WPAFB OH (937-255-7886), 10 November 1998.

[14] E-mail from Jennifer DeWalls, Lead Engineer, GDLS, Warren, MI to LtCol Dan Desjardins, AFRL/HECV, Wright-Patterson AFB OH, 20 September 2005. Also, telecon with Mr. Don Howe, Stryker PM, GDLS, on or about same date.

[15] Data on Remote Weapons Display (M151 Protector Fire Control Unit for Stryker) provided by Pal Andersen, Kongsberg, Sweden (+47 32 28 62 80) to LtCol Dan Desjardins, AFRL/HECV, WPAFB OH (937-255-4079), 15 September 2005.

[16] On-site visit by Maj Dan Desjardins, AFRL/HECV, WPAFB OH (937-255-4079), escorted by TSgt Roger M. Henry, Jr., Information Security Officer, HQ US Space Command, Peterson AFB CO (719-573-4098), 7 August 2001. TSgt Henry is the POC for computor monitors (e.g., C2 AS Workstations), while MSgt Brown in J6, is identified as the POC for questions on display purchases and performance.

[17] E-mail from Mr. Jeff Brunson, Chief Engineer, ASC/RABP, WPAFB OH (937-255-0121) to Maj Dan Desjardins, AFRL/HECV, WPAFB OH (937-255-4079), 17 November 2000.

[18] Spreadsheet: "Rockwell Collins Remote Control and Remote Indicator Installations," dated 10-26-01, sent by Mr. J.E. Smith, ARC-210 Program Manager, Rockwell Collins Government Systems, Ceder Rapids IA (319-295-5942) to Maj Dan Desjardins, AFRL/HECV, WPAFB OH (937-255-4079), January 14, 2002.

[19] Person-to-person conversation between Lt Col Brian Bergdahl, Commander, 15th Reconnaissance Squadron, Nellis AFB NV and Maj Dan Desjardins, AFRL/HECV, WPAFB OH (937-255-4079), 1 December 2000. Lt Col Bergdahl also confirmed the deployed number of Predator control stations and the definition of "DEMPC."

[20] "Optical Performance of SMFD with 12.1" Ruggedized Hydis Display," November 17, 2002 provided by Dr. Ragini Saxena, Sr. MTS, Northrop Grumman Corp., Navigation Systems (818-712-7286) to LtCol Dan Desjardins, AFRL/HECV, WPAFB OH (937-255-4079), 14 July 2004.

[21] E-Mail from Mr. Dale Green, Controls and Displays Group Leader, Lockheed Martin, Owego NY (607-751-2574) to Maj. Dan Desjardins, AFRL/HECV, WPAFB OH (937-255-4079), 10 May 1999. The message verified the number, size and resolution of "Smart" and "Dumb" MFDs and their location within the SH-60R platform.

[22] Telecon between Mr. Marty Conden, Lockheed-Martin Common Avionics Program Office, Owego NY (???) and Maj Dan

Desjardins, AFRL/HECV, WPAFB OH (937-255-7886), 15 December 1998.

[23] E-mail from Mr. Dave Klinchurch, Director of Sales and Marketting, CMC Electronics, Inc., Sugar Grove, IL (630-466-2114) to Maj Dan Desjardins, AFRL/HECV, WPAFB OH (937-255-4079), 4 April 2003.

[24] E-mail from Mr. Jim Bottone, SINCGARS Program Manager, ITT A/CD, LaGrange IL (260-451-5033) to Maj Dan Desjardins, AFRL/HECV, WPAFB OH (937-255-4079), 23 October 2002.

[25] E-mail from Mr. Jim Happel, Marketting Manager, Grayhill, LaGrange IL (708-482-2186) to Don Parker, ITT; Don Parker to Jim Bottone, ITT SINGARS PM, to Maj Dan Desjardins, AFRL/HECV, WPAFB OH (937-255-4079), 15 July 2002.

[26] E-mail from Mr. Robert Waage, Elbit Fort Worth TX (817-234-6600), including Prime Item Development Specification RDH-AR-268E, "Aviator's Night Vision Imaging System Heads Up Display (ANVIS/HUD) System," sent to LtCol Dan Desjardins, AFRL/HECV, WPAFB OH (937-255-4079), 18 June 2004.